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How Linkages Fuel the Fire: The Transmission of Financial Stress across the Markets

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Abstract

This paper develops an indicator of financial stress transmission, called Financial Stress Spillover Index (FSSI), to monitor the condition of financial system and to identify periods of excessive spillover that may lead to financial instability. Specifically, using the “spillover index” approach of Diebold and Yilmaz (2012), we modify and extend the financial stress indices proposed by Oet et al. (2011) to track both *total* and *directional* stress spillovers across the U.S. equity, debt, banking, and foreign exchange markets. Unlike other previous studies, the important linkages among these four major financial sectors in an interconnected world are directly taken into account by considering the average and time-varying connectedness of each individual market. The evidence suggests that there are important stress episodes and fluctuations across markets; the total cross-market stress spillovers were rather limited until the onsets of financial crises. As the crises intensified, so too did the financial stress spillovers; with significant stress carrying over from debt and equity markets to the others. In addition, our results indicate that FSSI has a significant predictive power for the economic activity and provides useful information for dating financial crisis.

JEL classification: G01; C03

Keywords: Banking; financial crises; financial stress transmission; spillover index

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1. Introduction

The global financial crisis has contributed to the meltdowns of financial markets and the continued economic downturns around the world, and has increased the attention of academics and policymakers on financial stability (Oet et al., 2011; Holló et al., 2012). The Chairman of the Federal Reserve Board of Governors, for instance, recently emphasized that *“The crisis has forcefully reminded us that the responsibility of central banks to protect financial stability is at least as important as the responsibility to use monetary policy effectively in the pursuit of macroeconomic objectives.”*¹ This has in turn motivated many central banks and financial authorities throughout the world to develop a range of indicators to help them monitor and assess the current state of instability or “stress” in the financial system, and take an appropriate regulatory action as necessary. Such a real-time monitoring and early detection system is very important and is considered as the necessary first step in the development of an “early warning system”, giving policymakers time to prevent or mitigate a potential financial crisis, and to counteract its effects on the economy.²

Previous attempts in the development of stress indicators have focused primarily on a range of methodological issues relating to (i) the selection and transformation of relevant variables, (ii) frequency of data, (iii) aggregation methods, and (iv) assessment criteria for the proposed indices (Louzis and Vouldis, 2011; Ishikawa et al., 2012). Most of these studies utilize the market-based or balance sheet data to construct indicators for several different financial sectors and then aggregate them into a composite index of systemic stress to provide critical

¹ “The Effects of the Great Recession on Central Bank Doctrine and Practice.”, Ben S. Bernanke (2011), The Federal Reserve Bank of Boston, 56th Economic Conference.

² Oet et al. (2013) present an example of such “early warning systems” designed for the identification of systemic banking risk in the U.S financial system., which they refer to as “SAFE” (Systemic Assessment of Financial Environment).

insights into the “aggregate” level of strains and imbalance in the whole financial system.³ According to Louzis and Vouldis (2011), there are as many as 13 financial stress indices of varying frequency currently available for tracking the level of stresses in the financial systems around the globe.⁴ One of the first and most influential composite indices of financial stress was introduced by Illing and Liu (2006). They constructed a daily financial stress index for Canadian financial system by exploring several different ways of combining raw variables into a composite index (e.g., variance-equal weighting and principal component methods); and selected the indicator that performs best in capturing crisis events identified by an internal survey within the Bank of Canada. Another composite index of financial stress that has attracted widespread attention is the one developed by Hakkio and Keeton (2009). Following the approach of Illing and Liu (2006), they used principal component analysis of 11 variables to create a monthly index for the U.S. economy in order to capture the essential features of a financial crisis. Using the variance-equal weighting of 12 standardized financial variables, Caldarelli et al. (2011) at the International Monetary Fund (IMF) compute a monthly financial stress index for seventeen advanced economies. Building on a probit regression of 16 financial market indicators, Grimaldi (2010) from the European Central Bank (ECB) presents a similar weekly financial stress index for the euro area. In a study directly related to this paper, economists at the Federal Reserve Bank of Cleveland (Oet et al., 2011) integrate 11 market-based variables from four most important segments of the financial system (equity, debt, banking, and foreign exchange markets). A separate financial stress index is calculated for each of these four sectors before aggregating the individual sub-indices into a composite index (the Cleveland Financial Stress Index, CFSI) by applying the time-varying credit weighting method.

³ Although there is no consensus on the precise definition of financial stress, it is usually interpreted as “*the risk that financial instability becomes so widespread that it impairs the functioning of a financial system to the point where economic growth and welfare suffer materially*” (Holló et al., 2012, p. 8).

⁴ See Louzis and Vouldis (2011) and Ishikawa et al. (2012) for more detailed reviews on the constructions and the desirable features of different financial stress measures that are currently available in the literature.

Evidently, since the global financial and economic crisis, the development of financial stress measures has been an expanding area for both academic and regulatory research. However, despite the widespread attention given to the development of financial stress index, the majority of studies have focused exclusively on constructing an “aggregate” index in assessing the overall level of stress in the global financial system. With an exception of Oet et al. (2011), there has been little research on designing a financial stress indicator for each of the four important sectors in a well-functioning financial system (equity, debt, banking, and foreign exchange markets), and in particular we can identify only a limited number of studies on the potential interaction and transmissions of financial stresses across these major sectors.⁵ This is somewhat surprising given that the growing concern that *“financial stress is more systemic and thus more dangerous for the economy as a whole if financial instability spreads more widely across the whole financial system”* (Holló et al., 2012, p.1).⁶

In order to address some of these issues, this paper builds on the work of Oet et al. (2011) and Diebold and Yilmaz (2012) and proposes an indicator of financial stress transmission, which we call “Financial Stress Spillover Index (FSSI)”, to assess the condition of financial system and to identify periods of excessive spillover that may lead to financial instability. Specifically, using the “spillover index” approach of Diebold and Yilmaz (2012), we modify and extend the financial stress indices proposed by Oet et al. (2011) to track both the *total* and *directional* stress spillovers across the U.S. equity, debt, banking, and foreign exchange

⁵ Louzis and Vouldis (2011) and Holló et al (2012) are other studies in the extant literature that have attempted to incorporate the possible interaction of financial stresses between different market segments by aggregating individual stress indicators from the perspective of standard portfolio theory. However, they only considered the cross-correlations between individual stress indicators and, thus, did not directly address the nature and direction of stress transmissions or spillovers. More importantly, the “origin” of financial stress is not clearly identified.

⁶ A study by the economists at the International Monetary Fund (IMF, 2009) “How linkage fuel the fire: the transmission of financial stress from advanced to emerging economies” finds that financial crises in advanced economies have passed through strongly and quickly to emerging economies.

markets. In contrast to other studies (including Oet et al., 2011), the important linkages among the major financial sectors in an interconnected world are directly taken into account in this paper by considering the average and time-varying interconnectedness of each individual market's stress indicators.

Taken together, this paper adds to the existing literature in a number of ways. First, unlike other previous studies, we develop an index of financial stress that incorporates the interconnectedness and spillover of stress across major market segments to provide an early warning system for emergent financial crisis. Second, this paper presents the first attempt to identify the “origin” of systemic stress by estimating “directional” FSSI and to detect the so-called systemically important financial markets. Third, given the evolutionary nature of financial stress, the conditional version of our FSSI tracks the time-varying movements of both total and directional stress spillovers. Finally, the FSSI introduced in this paper provides policymakers and regulators with useful information for dating financial crisis and predicting economic activity.

The findings of this paper are important in understanding the level and transmission mechanism of financial stress across the major market segments and are of significant relevance to the market regulators in formulating effective policies to tackle financial stress transmission, particularly during the turbulence periods. However, we also question how the ‘scapegoating’ of one particular financial sector might serve to distract attention both from the failings of other sectors and from the central problems inherent in the operations and interconnectedness of the financial system as a whole.

The remainder of the paper is organised as follows. Section 2 describes the data and methodology, and examines both conditional and unconditional transmission of financial stress across markets. Section 3 evaluates the practical applications of our FSSI in dating the past episodes of financial stress and in predicting future economic activity. The channels through which the transmission of financial stress can affect economic activity are also examined in this section. Finally, Section 4 concludes the paper.

2. Construction of Financial Stress Spillover Index (FSSI)

Motivated by the extant financial stress literature, and using the financial stress indices of Oet et al. (2011) and the spillover index methodology proposed by Diebold and Yilmaz (2012), this section constructs an indicator named Financial Stress Spillover Index (FSSI) to track the comovement and transmission of financial stress across four major U.S. financial sectors: equity, debt, banking and foreign exchange markets. The remainder of this section proceeds as follows. We begin by describing the data and methodology in Section 2.1, and in Section 2.2, we calculate the level of both *total* and *directional* spillovers over our sample period.

2.1 Data and Methodology

Cleveland Financial Stress Indices

As a direct response to analytical demand generated by the global financial crisis, many alternative indices have been recently developed by central bankers and financial economists to measure the current level of strains and stress in the whole financial system. For example, the Federal Reserve Bank of Cleveland has developed such a tool in Oet et al. (2011), called “Cleveland Financial Stress Index (CFSI)”. Unlike many other financial stress indices that are available in the literature, the CFSI incorporates information from a number of financial markets to derive a measure of financial system stress on a continuous basis. Specifically, the

CFSI is constructed using daily data from 11 components reflecting the conditions in four major financial sectors in the U.S.: equity, debt, banking, and foreign exchange markets. Yet, as many other widely used measures, CFSI again focuses on the “size” aspect of stress and does not sufficiently address the “interconnectedness” nature of financial stress i.e., stress generated in any of financial sectors can quickly be carried over to others, affecting the financial system as a whole.⁷ Thus, building upon on the indices developed by Oet et al. (2011), this paper develops a new indicator of financial stress transmission, called Financial Stress Spillover Index (FSSI), to directly address the concern that financial stress is more dangerous for the economy when it spreads across the financial system (Holló et al., 2012). In the following, we first provide a brief description on the selection of variables, the weighting schemes, aggregation methods, and the economic interpretation of CFSI as well as for its four market-specific sub-indices.⁸

The CFSI and the sub-CFSIs are constructed from a set of 11 market-based indicators for four major market segments (i.e., equity, debt, banking, and foreign exchange markets). Specifically, for the *equity* market sub-CFSI, Oet et al. (2011) derive the stock market crashes indicator (calculated as a ratio of the current S&P500 index value relative to its maximum over the previous year) to gauge the risk and stability of stock market. Likewise, the ratio of the current value of the traded-weighted U.S. dollar exchange index relative to the maximum over the previous year is used to track the level of anxiety and uncertainty in the *foreign exchange* market. Most of the remaining CFSI components are, however, calculated as

⁷ We thank the anonymous reviewer for the suggestion that a significant amount of foreign exchange, equity and debt market transactions are actually done by banks on behalf of clients and on their own accounts. Thus, these markets could be highly connected with the banking industry. A further examination of why such interconnectedness and spillover might exist is worthy of a study, but is beyond the scope of this paper.

⁸ Oet et al. (2011) contain a very detailed description of the construction of their CFSI index, and its comparison of many other financial stress indices that are available in the literature. Data on CFSI and its sub-indices are available at http://www.clevelandfed.org/research/data/financial_stress_index/.

spreads. For example, for the *debt* market, the following five indicators were used to capture the difficulty in acquiring liquidity/credit for both government and corporations:⁹

- Commercial paper-T-bill spread: difference between 90-day commercial paper and 90-day treasury yield, measuring short-term risk premium on financial companies' debt.
- Treasury yield curve spread: difference between three-month and 10-year T-bill yields, capturing the long-term uncertainty and short-term liquidity.
- Liquidity spread: difference in bid and ask prices on three-month T-bills, reflecting the liquidity and associated stress in financial markets.
- Corporate bond spread: difference of 10-year T-bill yield and 10-year Moody's Aaa-rated corporate bond yield, tracking the perception of risk in corporations of all sectors.
- Covered interest spread: difference between the 90-day U.K. and U.S. T-bill yields, containing information about the uncertainty in government bond markets.

To measure the strain and weakness in the *banking* sector, a further four indicators were used:

- Financial beta: sensitivity of S&P 500 Financials share prices to movements in share S&P 500 index, signalling the relative volatility of share prices in the banking sector.
- Bank bond spread: difference between 10-year T-bill yield and 10-year A-rated bond yield, capturing the perception of risk in banks issuing A-rated bonds.
- Interbank liquidity spread: difference between the three-month LIBOR and T-bill rates, reflecting the counterparty risk in interbank lending i.e., the so-called TED spread.
- Interbank cost of borrowing: difference three-month LIBOR and federal funds rates, measuring the degree of apprehension with which banks loan to one another.

⁹ Appendix A provides a summary of the calculation methods and the significance of all 11 financial indicators that are used in the computation of CFSI and its four sub-indices.

Oet et al. (2011) normalised these raw indicators and then aggregated them into their composite CFSI and four sub-CFSIs by applying a dynamic weighting method that captures the quarterly financing flows through the four markets concerned. As the main objective of this paper is to examine the “interconnectedness” of stress in different market segments and to trace the “origin” of elevated stress, we plot the four individual markets’ financial stress (as measured by sub-CFSIs) in Figure 1 and provide summary statistics of the log sub-CFSIs in Table 1. For better illustration, each sub-indices is rescaled to a range of 0 to 100 (i.e., sample peak is 100 and sample trough is 0). The higher the value of the index, the more stressful it is in that financial sector. Our sample period ranges from October 1991 to November 2011, covering the recent global financial crisis of 2007-2011. Several interesting facts emerge; (1) all four sub-CFSIs fluctuates substantially over time, with their peaks occurred in the periods corresponding to crisis events; (2) equity and debt markets appear to be the more ‘stressed’ sectors than others; (3) financial stress indices are rather persistent exhibiting significant serial correlation (as indicated by significant LB statistics); and (4) financial stress is particularly high during the global financial meltdown in 2007/09, with banking and foreign exchange stress levels displaying sudden jumps. Since the variables in the vector autoregression (VAR) must be stationary, we conduct tests for the presence of a unit root in the log sub-CFSIs series. In addition to the well-known augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, we also present the DF-GLS unit root test proposed by Ng and Perron (2001) which has been shown to contain better properties than the conventional unit root tests (Elliott et al., 1996). The test results reported in Panel B of Table 1 are consistent with those of Oet et al. (2011) and indicate that the sub-CFSIs are all stationary at one percent level.

Finally, to gauge the initial idea on the interconnectedness of financial stress in various markets, we estimate their correlation coefficients during our sample period. The results reported in Panel C of Table 1 show that there are positive and statistical significant correlations among the four markets (with the Banking-Forex pair as the only exception). Nonetheless, the interaction and transmission of financial stress may give rise to correlation patterns that are more complex than a simple correlation coefficient can capture. It is, therefore, interesting and informative to further investigate the extent to which financial stress originated in one market affects the others, and to identify the channels through which a market's financial stress spillovers across the whole financial system.

Diebold and Yilmaz's Spillover Index

Several approaches have been suggested in the literature to investigate the co-movements and spillovers of key financial market variables (e.g., asset return and volatility), however our analysis requires a methodology that allows us to distinguish between idiosyncratic shocks to each market's financial stress and the spillover of shocks across markets, and more importantly, to identify how much shocks to financial stress in each market considered affect that of other markets. In other words, we need an approach that captures how quickly financial stress builds up and spreads across various markets over time. For this we follow the methodology set forth in Diebold and Yilmaz (2009, 2012, hereafter DY), generating what they term a *spillover index*.¹⁰ The spillover index is built upon the familiar notion of variance decomposition associated with an N-variable vector autoregression (VAR). In the following, we provide a brief overview of the DY's spillover index methodology.¹¹

¹⁰ While it is beyond the scope of this paper, it will be interesting in future work to understand better the relationship of DY's spillover measure to other widely used methods based, for example, on the multivariate GARCH models. See Gagnon and Karolyi (2006) for a survey on the literature of comovement in asset prices and volatility across markets and the development of econometric methodology to model these dynamics.

¹¹ For a more detailed explanation on the construction of this index, see Diebold and Yilmaz (2009, 2012). They use this methodology to characterize volatility spillover across US stock, bond, foreign exchange and

Consider a covariance stationary of N-variable VAR of p th-order, $x_t = \sum_{i=1}^p \Phi_i x_{t-i} + \varepsilon_t$, where $\varepsilon_t \sim (0, \Sigma)$. In the context of current paper, $x_t = (x_{1t}, x_{2t} \dots x_{nt})$ represents a vector of financial stress, Φ is a $N \times N$ parameter matrix and ε is the vector of independently and identically distributed error terms with zero mean and variance of covariance matrix Σ . The moving average (MA) representation is $x_t = \sum_{i=0}^{\infty} A_i x_{t-i}$ where A_i is an $N \times N$ coefficient matrices following the recursion $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \dots + \Phi_p A_{i-p}$, with A_0 as an $N \times N$ identify matrix and $A_i = 0$ for $i < 0$. Variance decomposition allows one to decompose the fraction of H -step-ahead forecast error variance into *own variance shares* and *cross variance shares*, or *spillovers*. The “own variance shares” refer to the part of the forecast error variance in forecasting x_i due to shocks to x_i itself for $i=1,2,\dots,N$, whereas “cross variance shares” represent the part that is attributable to shock from another variable x_j for $j=1,2,\dots,N$ and $i \neq j$. Diebold and Yilmaz (2009) proposed to use Cholesky-decomposition to decompose the variance. However, Cholesky-decomposition is dependent on the ordering of the variable. Diebold and Yilmaz (2012) resolve this ordering problem by exploiting the generalized VAR framework of Koop, Pesaran and Potter (1996) and Pesaran and Shin (1998), KPPS, producing the variance decomposition invariant to ordering.

More specifically, KPPS H -step-ahead error forecast variance decomposition is given by:

$$\theta_{ij}^s(H) = \frac{\sigma_{ii}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h' \Sigma e_j)} \quad (1)$$

commodities markets. Nevertheless, volatility is simply one indicator of stress and high volatility does not necessarily arise in stressful periods. As Grimaldi (2010, p.5) argue “*with high financial spreads signifying something amiss, for example that no trade is taking place, the volatility might be very low but stress very high*”.

where Σ represents the variance matrix for error vector ε , σ_{ii} is the standard deviation of the error term for i th equation, and e_i is the selection vector with one for the i th element and zero otherwise. Unlike Cholesky factor orthogonalization, the KPPS H -step-ahead error forecast variance decomposition does not try to orthogonalize the shock but instead allows for correlated shocks and accounts for them appropriately using the historical distribution of the errors. However, as emphasized by Diebold and Yilmaz (2012, p.58), “*As the shocks to each variable are not orthogonalized, the sum of contributions to the variance of forecast error (that is, the row sum of the elements of the variance decomposition table) is not necessarily equal to one.*” Thus, each entry of the variance decomposition matrix in equation (1) needs to be normalized so that the information from the variance decomposition matrix can be used.

The normalization of the entry for the variance decomposition matrix by the *row* sum gives

$$\tilde{\theta}_{ij}^g(H) = \frac{\theta_{ij}^g(H)}{\sum_{j=1}^N \theta_{ij}^g(H)} \quad (2)$$

where $\sum_{j=1}^N \tilde{\theta}_{ij}^g(H) = 1$ and $\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H) = N$.

Using the normalized entry for the generalized variance decomposition matrix in equation (2), Diebold and Yilmaz (2012) construct the *total spillover index* as follows:

$$S^g(H) = \frac{\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H)}{\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H)} \times 100 = \frac{\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H)}{N} \times 100 \quad (3)$$

In addition to the total spillover index, information from KPPS variance decomposition also enables us to measure the directional spillovers across the markets in order to understand how much shocks to the financial stress are being carried across the major financial sectors. In

particular, the *directional spillover received* by market i FROM all other markets j can be calculated as:

$$S_{i\bullet}^g(H) = \frac{\sum_{j=1, i \neq j}^N \tilde{\theta}_{ij}^g(H)}{\sum_{j=1}^N \tilde{\theta}_{ij}^g(H)} \times 100 \quad (4)$$

Similarly, the *directional spillover transmitted* by market i TO all other markets j can be measured as:

$$S_{\bullet i}^g(H) = \frac{\sum_{j=1, i \neq j}^N \tilde{\theta}_{ji}^g(H)}{\sum_{j=1}^N \tilde{\theta}_{ji}^g(H)} \times 100 \quad (5)$$

Finally, one can also obtain the *net directional spillover* from market i to all other markets j by calculating the difference between equations (4) and (5) as, TO - FROM:

$$S_i^g(H) = S_{\bullet i}^g(H) - S_{i\bullet}^g(H) \quad (6)$$

This *net directional spillover* provides critical information about how much (in net terms) each of the four markets (equity, debt, banking, and foreign exchange) contributes to financial stress transmission within the overall financial system. The generality of all these DY's spillover measures (both total and directional) is often useful and, in the next section, we use these to derive an intuitive measure of financial stress spillovers (called Financial Stress Spillover Index, FSSI) to study the level and trend of financial stress interdependence in the four major U.S. financial sectors: equity, debt, banking, and foreign exchange markets. The higher the FSSI values imply that a larger proportion of the financial stress in any one market can be accounted for by shocks originated in other markets.

2.2 Linkages and Transmission Mechanisms

Previous section has illustrated how the DY (2012) spillover index framework can be used to construct an indicator of financial stress transmission to monitor the levels of financial stress spillovers across major financial sectors. In this section, we present both *total* and *directional* spillover indices and examine their time-series dynamics over the sample period. Two associated tools of DY's methodology are spillover table and spillover plots. However, as emphasized by DY (2012), while the spillover table provides a useful summary of the total (i.e. average) spillover behaviour over the entire sample, it is unlikely that this can accurately capture the secular and cyclical movements in spillovers which are particularly important when examining financial market evolution and turbulences. Thus, in addition to reporting the unconditional full-sample spillover table, we also present the *time-varying* conditional spillover plots in order to assess the nature and direction of spillover variation over time.

Unconditional Full-sample Stress Spillover

Following DY (2012), we first apply a second-order VAR ($p=2$) with 10-step-ahead forecasts to do the generalized variance decomposition of financial stress in four U.S. financial sectors (equity, debt, banking and foreign exchange markets).¹² Table 2 provides the average levels of both total and directional spillovers over the full-sample period. The off-diagonal column sums (labelled Directional TO others) and row sums (labelled Directional FROM others) are the 'TO' and 'FROM' directional spillovers, and the 'TO – FROM' differences are the NET directional spillovers. The *total* spillover index is reported in the lower corner of the table. As can be seen from the table, the total financial stress spillover is not sizeable (the total spillover index is 16.3%), indicating that, on average, over our entire sample, less than a quarter of the total stress variations in the U.S. financial system is explained by the cross-market stress spillovers, while the remaining 83.7% variations is caused by idiosyncratic

¹² As robustness checks, we also calculate the total spillover indices for fourth-order VAR with 5-step forecast horizons. The result (not included in the paper but available on request from authors) shows that, irrespective of the choices of order of VAR or the forecast horizon, the levels of spillover are rather similar.

shocks to its own stress level. In terms of the *directional* spillovers transmitted TO others, debt market appears to be the sector that contributed the most (31%) to other markets' stress, followed by equity (17%), Forex (9%) and Banking (8%). According to these full-sample directional spillover measures, banking sector barely transmits any financial stress to other financial sectors. In contrast, judging on the directional spillovers received FROM others, banking seems to be the sector that received the most financial stress from others (38%). The net directional spillovers (TO – FROM) confirms that banking sector (-30%) is the net recipient of financial stress spillover over the full sample. Debt (14%) and Equity (12%), on the other hand, are the net transmitters of financial stress. In addition, the results also indicate that the foreign exchange market is the most exogenous market as its 95% of variations are due to the shock generated in its own market.

These findings are in stark contrast with the claim that banking industry plays a deciding role in the development of systemic stress and financial crises (see, e.g., Allen and Gale, 2007; Rochet, 2008). In particular, in responses to the recent meltdowns of global financial system, financial analysts and investors have repeatedly blamed the banking industry and large financial institutions for causing and transmitting the unusually high level in anxiety and difficulties that rippled through the economy (Ahmed, 2010; Orol, 2011). According to a recent survey conducted in the UK, a significant majority of the public put the blame at the door of the 'banking industry' for the current financial problems and demand the further strengthening of the bank supervision from regulators in order to safeguard for the future. The main argument levelled against the banks is the substantial exposures that the banking institutions have taken on the high-risk investment products as well as the deficiencies in the bank management and control. Given its prominent connection with different segments of financial systems, the vulnerability of the banking system can quickly lead to the erosion of

the entire financial system. Despite these concerns, our results raise an important question on whether the ‘scapegoating’ of one particular financial sector can help policymakers reaching reliable policy conclusions. On the contrary, we argue that this might serve as a distraction to the regulatory attention both from the failings of other sectors and from the central problems inherent in the operations and interconnectedness of the financial system as a whole.

Conditional Time-varying Stress Spillover

In this section, we calculate the conditional spillover indices by re-estimating our second-order VAR weekly, using a 100-week rolling estimation window, in order to assess the time-varying nature of both total and directional stress spillovers.¹³ The conditional *total* stress spillover plot is presented in Figure 2. The behaviour of our spillover index over various business cycles can also be informative. Intuitively, a well-defined indicator should correlate with and be a good leading indicator of recessions. Thus we use the National Bureau of Economic Research (NBER) business cycle indicators to identify recessions in our sample. Several important observations can be drawn. First, as expected, the spillover index varies over time. Starting at a value of slightly above 20% in the first window, the spillover index fluctuates mostly between fifteen and thirty percent. However, during the onsets of U.S. Subprime crisis and Eurozone debt crisis, the cross-market stress spillovers show very sharp jumps and exceed the forty percent mark. Second, while the index fluctuates over time, one can differentiate between several cycles, typically corresponding to the crisis events. Finally, the spillover index also tends to increase rapidly during the beginning periods of recessions

¹³ To check the sensitivity of our results, we also plot the total spillover indices based on 75-week rolling window with 10- and 5-week forecast horizons. The figures presented in Appendix B1 show that the total spillover plot is not sensitive to the choices of window size or the forecast horizon; the spillover indices appear to be following similar patterns. In addition, we also present Appendix B2 an alternative spillover plot based on the Cholesky variance decomposition rather than the generalized variance decomposition used in DY (2012).

(indicated by shaded bars in the figure).¹⁴ In Section 3 we conduct a more detailed analysis on how the financial stress spillovers affect the overall economic activity and the evolution of financial crises.

In addition to the conditional *total* spillover plot, we also present the time-varying *directional* spillover plots in order to allow policymakers to derive an early-warning system for identifying the ‘origin’ of stress and to take appropriate regulatory actions as necessary. We focus on the *net directional* spillover plots presented in Figure 3 to demonstrate the time-varying differences between directional TO and directional FROM spillovers (i.e., ‘TO – FROM’) for each financial market.¹⁵ Consistent with the “unconditional” findings reported in Table 2, these time-series plots are quite revealing about the net spillovers of debt and equity markets to others. The high net spillovers from the debt to other markets are most evident after the 2000s and around the burst of Dot-Com bubble, the intensification of subprime crisis and the recent meltdown of global financial markets. Equity market was also an important source of financial stress spillovers, with its net spillovers reaching close to 15% during the 2007-08 global financial turmoil. However, since late 2008 its role was reversed and received almost 10% of stress from others in November 2011. The banking industry, on the other hand, was a net recipient of financial stress spillover over most of the sample period. Figure 3 also confirms that foreign exchange market is an exogenous market, contributing very limited stress to the financial system (with the exception of a brief spell in the second half of 2009).

Taken together, the evidence thus far suggests that there are important stress episodes and fluctuations across markets; the total cross-market stress spillovers were rather limited until

¹⁴ It should be noted, however, that the spillover index also recorded significant upward movements during some, but not all, expansion episodes.

¹⁵ For completeness, the plots of the gross directional stress spillovers transmitted TO others and received FROM others are also presented separately in Appendices C1 and C2.

the onsets of financial crises. As the crises intensified, so too did the financial stress spillovers; with significant stress carrying over from the debt and equity markets to others. These findings are important in understanding the level and transmission mechanism of financial stress across the major market segments and are of significant relevance to the market regulators in formulating effective policies to tackle financial stress transmission, particularly during the turbulence periods.

3. Applications of Financial Stress Spillover Index (FSSI)

3.1 Monitoring Financial Stress Transmission

The main objective of this paper is to construct an index of systemic stress to help policymakers monitor and understand the severity of financial stress transmission across financial markets, and take an appropriate regulatory or supervisory action as necessary. However, according to Holló et al. (2012), it might not be easy to identify situations where systemic stress level is high enough to threaten the financial stability and economic growth. Several approaches have been suggested in the literature to tackle this problem. The most widely used approach is to benchmark the current level of stress against its historical trend level (see, e.g., Illing and Liu, 2006; Melvin and Taylor, 2009; Caldarelli et al., 2011).

We employ a similar approach to distinguish between different categories of spillover severity. First, we compute a measure of how many standard deviations (SD) the current FSSI is away from its time-varying mean, the scored FSSI (Z_{FSSI}), by subtracting off a time-varying mean and dividing it by a time-varying standard deviation.¹⁶ Then, we classify the severity of stress spillover by the extent to which the scored index exceeds its historical mean. Specifically, we assign Z_{FSSI} larger than 2 SD above the mean to the “severe spillover”

¹⁶ The time-varying mean is calculated using the moving average of 36 weeks’ values of FSSI, while the time-varying standard deviation is computed by taking the square root of a 36-week moving average of the squared deviations from the time-varying mean.

category (regime A); Z_{FSSI} falling between 0.75 and 2 SD to the “moderate spillover” category (regime B); Z_{FSSI} falling between ± 0.75 SD of the mean to the “normal spillover” category (regime C); Z_{FSSI} below -0.75 SD of the mean to the “below-normal spillover” category (regime D).¹⁷ Such a rating system is important as it could provide policymakers with a useful tool to monitor episodes of financial stress spillovers, and to derive an “early warning system” for emergent crises. For instance, when significant stress originates in a certain market and spreads across to other sectors, the functioning of the overall financial system might be disrupted, triggering regulators to take appropriate supervisory actions as necessary. Thus, from the market regulators’ perspective, information about the transmission of financial stress across markets is perhaps more important than the detection of stress level in any individual market.

Figure 4 shows the scored FSSI and the associated Z_{FSSI} regimes. As indicated in the figure, Z_{FSSI} climbed into the “severe spillover” regime in the periods around the Russian default and Long-Term Capital Management (LTCM) crisis (October 1998), and the Enron / WorldCom accounting scandals (October 2002). The index also picked up an increasing stressful period at the beginning of Subprime Crisis (Summer 2007) and reached its highest value of 3.4 in May 2010 due to the widespread fear of a double-dip recession in the U.S economy. The growing concern about the Eurozone countries’, mostly the Greek, public debt has pushed the index near a value of 2.3 in May 2011. While the Z_{FSSI} has not moved back into this “severe spillover” regime since, it remained in the “moderate spillover” zone throughout 2011.

¹⁷ It should be noted, however, that this classification approach is not without its shortcomings. For instance, there is no consensus on how many standard deviations the index has to exceed its mean in order to be classified as “severe” stress spillover. Nonetheless, our choices of thresholds are comparable to those commonly used in the literature. Illing and Liu (2006) use a relatively high threshold of 2 SD above the mean, while Bordo et al. (2000) and Caldarelli et al. (2011) employ lower cut offs of 0.75 to 1.5 SD above the mean. Oet et al. (2011) and Holló et al. (2012) apply an alternative approach to endogenously estimate these thresholds using the threshold and Markov-switching VAR models.

3.2 Dating Financial Crisis Periods

The scored spillover index (Z_{FSSI}) tracks the periods of unusually high stress spillover reasonably well, suggesting that it could be a useful monitoring tool for market regulators. However, as Hakkio and Keeton (2009, p.28) note, *“Many users will find it useful to know if the index is higher than in some previous financial crisis with which they are familiar.”* Thus, this section uses an alternative way of assessing the level of stress spillover and compares the historical values of Z_{FSSI} to see whether peaks in the index occurred during the periods of past widely recognised financial crises. Similar to Oet et al. (2011) and Louzis and Vouldis (2011), we begin by constructing a chronology of financial crises (with their severities) based on the financial experts’ evaluation of a list of events that are widely considered to have significant influences on the U.S. financial system. In this regards, we use the financial expert surveys from the Federal Reserve Bank of Cleveland to identify the well-known financial crises that have attracted the attention of central bankers and policymakers.¹⁸

Figure 5 compares the experts’ ranking of several well-known financial crises with the movements of our Z_{FSSI} index. In these surveys, financial experts were asked to evaluate the level of stress and uncertainty that these systemic events had caused to the U.S. financial system in a scale of 0 to 4; larger value reflects the greater significance and concern. The figure indicates that our spillover index has a very high correlation to the occurrence of major financial crises. Many well-known financial crises such as the LTCM collapse, Dot-Com bubble burst, and Subprime crisis occurred approximately at the peaks of Z_{FSSI} index, suggesting that our index can be used to establish an objective method of crisis dating. In addition, Figure 5 illustrates that the unprecedented breadth and intensity of the Eurozone debt crisis coincide with the highest level of spillover in the U.S. financial system. Overall,

¹⁸Oet et al. (2011) use the results of this survey to select some alternative weighting methods used in the aggregation of their financial stress sub-indices. This approach has also been used in Illing and Liu (2006) and Louzis and Vouldis (2011) in evaluating the performance of their financial stress indices for Canada and Greece.

the picture depicted in Figure 5 supports the view that the Z_{FSSI} index allows one to derive a timely indicator for financial crises, accurately locate and date significant financial episodes that are of serious concerns to market regulators and financial experts.

3.3 Predicting Economic Activities

Previous sections have demonstrated how the FSSI (and the Z_{FSSI}) can help to monitor the levels of financial stress spillovers across markets, and how the index can be used to identify the periods of unusually high level of systemic stress or financial crises. The next important question to ask is whether a widespread transmission of financial stress could actually harm the economy and reduce the national economic activity. To address this question, we first examine the relationship between FSSI and a monthly index of national economic activity to see if increases in financial stress spillover have indeed led to decreases in economic growth. We then investigate the possible channels through which financial stress spillover can affect economic activity.

The linkage between FSSI and economic activity

As noted earlier, it is of interest to determine whether and to what extent the ‘interlinkage’ of financial stress (as measured by FSSI) affects the economic activity.¹⁹ We chose the Chicago Fed’s National Activity Index (CFNAI) as a measure of the overall economic activity because it has been shown that this index often provides useful information on the current and future courses of U.S. economic activity and inflation (Chicago Fed, 2012). The CFNAI is constructed using principal components of 85 monthly indicators for employment, production, personal consumption, sales & inventories, and corresponds to the economic

¹⁹ A growing number of studies have sought to identify the link between financial stress and the real economy and the channels through which financial stress can affect economic activity. See, for instance, Claessens et al. (2008), Hakkio and Keeton (2009), Davig and Hakkio (2010), Holló et al. (2012), and Cevik et al. (2013). This paper, however, focus on the ‘interlinkage’ of financial stress and its impact on economic activity.

activity index developed by Stock and Watson (1999). A zero value for the index indicates that the national economy is expanding at its historical trend rate of growth; negative values indicate below-average growth; and positive values indicate above-average growth. According to the Chicago Fed (2012), however, month-to-month movements can be volatile and the index's 3-month moving average provides a more consistent picture of the national economic growth.²⁰ Thus, the 3-month moving averages for both CFNAI and FSSI are plotted in Figure 6. The two indices show a negative correlation, moving in opposite directions throughout the period. The negative comovement is especially pronounced during the two U.S. recessions occurred in our sample period. Specifically, the contemporaneous correlation between FSSI and CFNAI is -0.25 and statistically significant at the 1% level.

Although there is a significant negative relationship between FSSI and the *current* state of the economy (CFNAI), it is difficult to judge whether our measure of financial stress spillover (FSSI) provides information about the *future* path of economic activity that is not already contained in other macroeconomic indicators. To provide evidence on this issue, we estimate the following regression model

$$ECONACT_t = \alpha + \sum_{i=1}^K \beta_i FSSI_{t-i} + \gamma' Z_{t-1} + \varepsilon_t \quad (7)$$

where ECONACT represents either the 3-month moving average value of the Chicago Fed's National Activity Index (CFNAI) or its four sub-indices for activity in production and income (P&I), employment, unemployment, and hours (EU&H), personal consumption and housing (C&H), and sales, orders & inventories (SO&I), in month t ; α is a constant term; $FSSI_{t-i}$ for $i = 1, 2, \dots, k$ denote lagged values of Financial Stress Spillover Index (FSSI) with corresponding coefficients β_i ; Z is a vector of additional explanatory variables including the

²⁰ "Background Information on the Chicago Fed National Activity Index", Chicago Fed (2012), available at http://chicagofed.org/digital_assets/publications/cfnai/background/cfnai_background.pdf. A further explanation of the CFNAI can be found at <http://chicagofed.org/webpages/publications/cfnai/index.cfm>.

first lagged value of dependent variable and other macroeconomic indicators (i.e., the Consumer Price Index (CPI) and the three-month Treasury bill rate) to control for other factors that might affect economic growth.²¹

Table 3 shows how well our FSSI can predict the future values of the nation's overall economic activity (CFNAI) as well as for the four broad categories of activity in P&I, EU&H, C&H, and SO&I. For each category of economic activities, Table 3 presents the adjusted R-square statistic, the sum of β coefficients on lagged values of FSSI, and a Wald test statistic testing the joint significance of these lagged values. We begin by presenting regressions that do not include other macroeconomic indicators contained in vector Z. If the null hypothesis $\beta_i = 0$ for $i = 1, 2 \dots k$ is rejected, we then examine the incremental improvement in the predictive ability of FSSI relative to using only the standard indicators in Z as predictors. For this we compute the *increment* to adjusted R^2 from adding lagged FSSI on a regression that includes only the control variables in Z and then test again the joint significance of FSSI lagged values.

The results indicate that our measure of financial stress connectedness (FSSI) on its own has a significant predictive power for the overall economic activity and for a variety of economic categories (with EU&H as the only exception). Lagged values of FSSI explain about 11 percent of variation in the three-month moving average of national economic activity (CFNAI), and almost 33 percent of the personal consumption and housing (C&H) expenditure. Even with additional control variables included, the lags of FSSI remain significant in explaining the variations in CFNAI, C&H, and SO&I activities. The incremental adjusted R^2 varies from 1 to 6 percent. As expected, the tests also show that the

²¹ Similar regression models are used in Ludvigson (2004) and Garrett et al. (2005) in assessing the predictive ability of consumer confidence on consumer spending at both national and state levels.

widespread transmission of financial stress (FSSI) leads to decreases in economic activity. Specifically, the sums of coefficients on lagged FSSI are mostly negative and statistically significant. This is consistent with the negative relationship between FSSI and CFNAI indicated in Figure 6. In addition, the values and significance of control variables indicate that overall economic activity is also influenced by the interest rate and inflation, and that there is a presence of positive autocorrelation in economic activities.

The sources of linkage between FSSI and economic activity

Taken together, the results from Table 3 suggest that FSSI has a modest but statistically significant predictive power for future economic activity. This is hardly surprising and supports the notion that rapid transmission financial stress across the financial system can slow economic activity through the increased uncertainty, increased cost of finance, and/or tighter credit standards (Hakkio and Keeton, 2009). To shed some lights on the ways in which financial stress spillover affects economic activity, we follow the approach of Hakkio and Keeton (2009) and compare the movements of FSSI with a measure of tightening of credit standards from the Federal Reserve's Senior Loan Officer Opinion Survey (SLOOS), along with a proxy for the level of market uncertainty derived from the Chicago Board Options Exchange's (CBOE) Volatility Index (VIX).²² The quarterly values of FSSI, SLOOS, and VIX are plotted in Figure 7. The figure suggests that our financial stress spillover index (FSSI), SLOOS and VIX tend to move together throughout the period. This tendency is most evident since late 2008 and around the two recessions. Specifically, during the periods of widespread transmission of financial stress across financial markets (FSSI), there is a noticeable increase in the market uncertainty (VIX) and tightening of the bank lending

²² The CBOE's VIX index has been considered by many to be the world's premier barometer of market volatility and investor sentiment. We obtain the quarterly values of VIX from Datastream and SLOOS from the website of Federal Reserve Board (FRB). Each quarter, SLOOS reports the net percentage of banks that said they have tightened credit standards over the previous three months. A detailed explanation of the SLOOS can be found on the FRB's website (<http://www.federalreserve.gov/boarddocs/snloansurvey/>).

standards (SLOOS). This seems to suggest that the high level of stress transmission within financial system impacts the macroeconomy through bank lending activity and uncertainty about the future prices of financial assets in general.

4. Conclusions

In this paper we have developed an indicator of financial stress transmission, “Financial Stress Spillover Index (FSSI)”, to better understand the current state of financial instability and to provide an early warning system for emergent crisis. Specifically, building on the work of Oet et al. (2011) and Diebold and Yilmaz (2012), we derived several conditional and unconditional measures capturing both level and transmission mechanism of stress across four major U.S. financial sectors (i.e., equity, debt, banking, and foreign exchange markets). The evidence suggests that there are important stress episodes and fluctuations across markets; the total cross-market stress spillovers were rather limited until the onsets of various financial crises. As the crises intensified, so too did the financial stress spillovers; with significant stress carrying over from debt and equity markets to others. In addition, our results also reveal that FSSI has a significant predictive power for future economic activity. Overall, these findings provide further evidence on the issue of “how linkages fuel the fire” and are of great significance to the financial authorities and policymakers who have a responsibility of ensuring financial stability and promoting economic growth. However, we also argue that “interconnectedness” of modern financial system had substantially increased the complexity and fragility of the financial network, and that ‘scapegoating’ of banking industry for the financial disaster might not be optimal in reaching reliable policy conclusions. On the contrary, this may distract regulatory attention both from the failings of other sectors and from the central problems inherent in the operation and interconnectedness of the financial system as a whole.

As with any empirical investigation, the results in this paper must be taken in context. We introduced a relatively simple and intuitive measure of financial stress transmission and applied them to the data from four U.S. markets.²³ Also, in Section 3.1 we classify the current state of systemic stress into just four regimes, while it may be more practical to allow for more different categories in such an interconnected world. Further research which seeks to resolve these issues may provide additional insights into the potential effects of financial stress linkages on the functioning of financial system and changes in economic activity. Furthermore, since a number of financial stress indices have been recently developed by central bankers and financial economists to measure the current level of strains and stress in the financial system, a comparative assessment of our FSSI against these alternative series of financial stress would be an interesting area for future research.

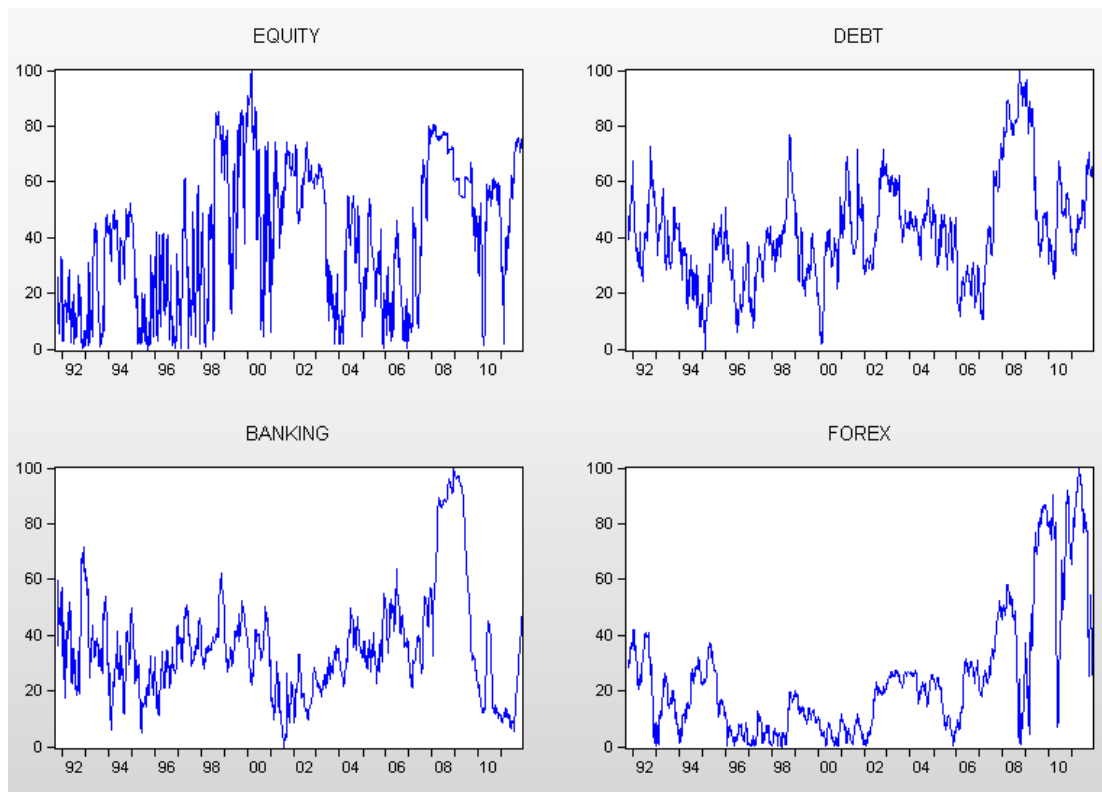
²³ As emphasized in Grimaldi (2010) and Holló et al. (2012), it would be rather unrealistic to expect that a single composite index can sufficiently characterise something as complex as the modern financial system.

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Figure 1: The Evolution of Financial Stress



Note: The financial stress indices (sub-CFSIs) developed by Oet et al. (2011) in reflecting the financial stress conditions of the equity, debt, banking, and foreign exchange markets in the U.S.

Table 1: Preliminary Statistics

	Equity			Debt			Banking			Forex		
Panel A : Summary statistics												
Mean	1.135			1.219			1.142			-0.180		
Std. Dev.	0.358			0.099			0.135			0.482		
Skewness	-0.983			-0.059			0.229			-0.691		
Kurtosis	3.085			3.244			3.392			3.205		
JB	169.88	***		3.23			15.94	***		85.53	***	
LB(Q)	802.231	***		986.814	***		987.362	***		944.981	***	
Panel B : Unit roots												
ADF	-6.7912	***		-4.1282	***		-4.2338	***		-4.0636	***	
PP	-7.8333	***		-4.2066	***		-4.3331	***		-4.7589	***	
DF-GLS	-5.0770	***		-3.8488	***		-2.6261	***		-3.4117	***	
Panel C : Correlation coefficients												
Equity	1.000											
Debt	0.292	***		1.000								
Banking	0.080	***		0.328	***		1.000					
Forex	0.087	***		0.281	***		-0.027			1.000		

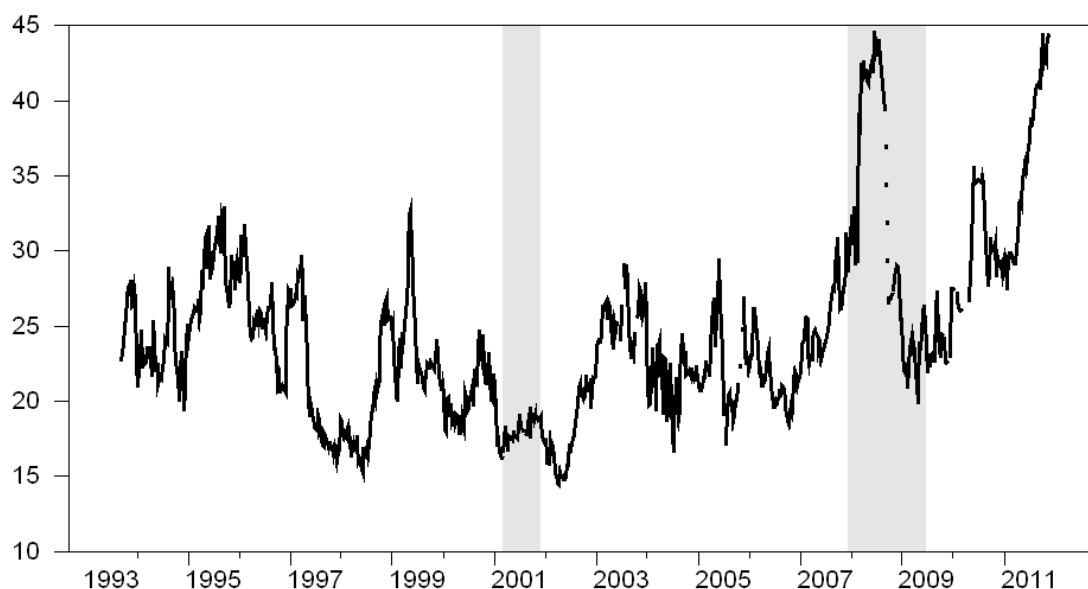
Notes: This table reports the sample mean, standard deviation, skewness and Kurtosis for the logarithm values of each sub-CFSIs; JB = Jarque-Bera test for normality and LB(Q) is the Ljung-Box Q test of serial correlation. The unit root tests include a constant term, with lag length determined by the Schwartz Information Criteria (SIC). Critical values for ADF, PP and DF-GLS tests are based upon MacKinnon (1996). *, **, *** denote significance at 10%, 5%, and 1% levels, respectively.

Table 2: The Full-sample Financial Stress Spillovers

	Equity	Debt	Banking	Forex	Directional FROM others
Equity	94.9	3.5	1.2	0.4	5
Debt	11.9	83.1	4.2	0.8	17
Banking	3.7	26.5	62.4	7.4	38
Forex	1.8	0.4	2.7	95.0	5
Directional TO others	17	31	8	9	Total Spillover Index (65/400): 16.3%
NET Directional Spillovers (TO – FROM)	12	14	-30	4	

Note: This table reports the full-sample (i.e. average) total and directional spillovers. The second-order VARs ($p=2$) with 10-step-ahead forecasts is used to do the generalized variance decomposition for 4 major U.S. financial sectors (equity, debt, banking and foreign exchange markets). The off-diagonal column sums (labelled Directional TO others) and row sums (labelled Directional FROM others) are the ‘TO’ and ‘FROM’ directional spillovers, and the ‘TO – FROM’ differences are the net directional spillovers. The total spillover index is given in the lower corner of the table.

Figure 2: Time-varying Financial Stress Spillovers, across Four Markets



Note: The total financial stress spillover index (FSSI) across four major U.S. financial sectors (equity, debt, banking and foreign exchange markets) is presented in this figure. The values are calculated by re-estimating the second-order VAR weekly, using a 100-week rolling estimation window with 10-week forecast horizon. Generalized variance decomposition method is used. Shaded areas represent NBER recessions.

Figure 3: Net Financial Stress Spillovers, across Four Markets

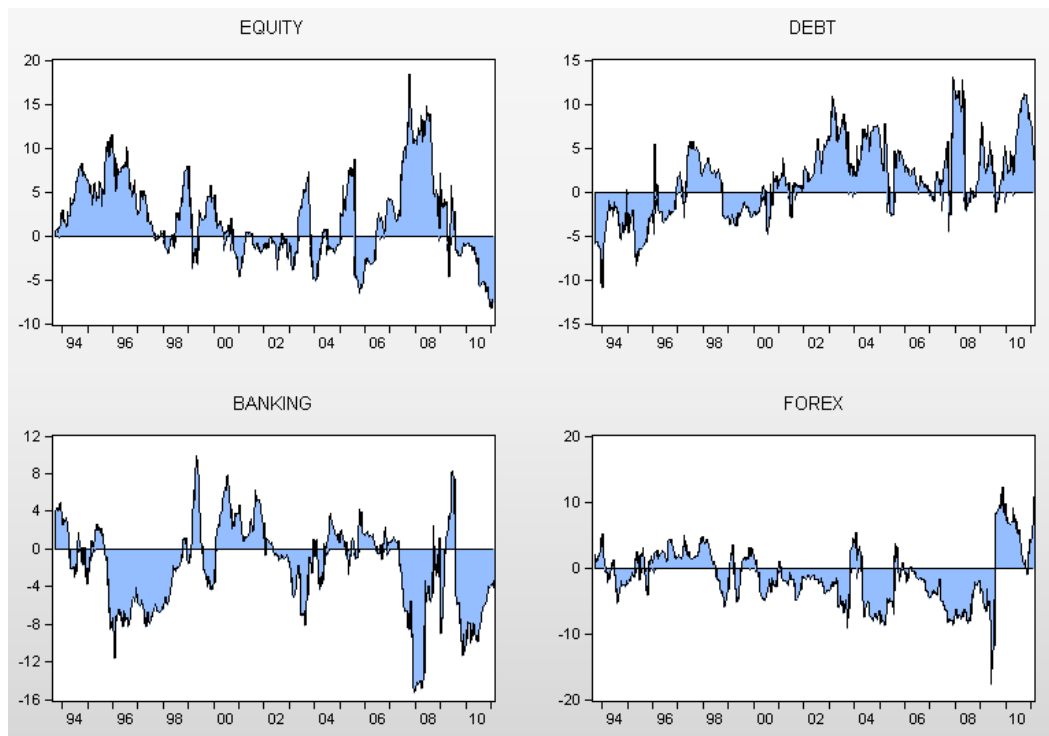
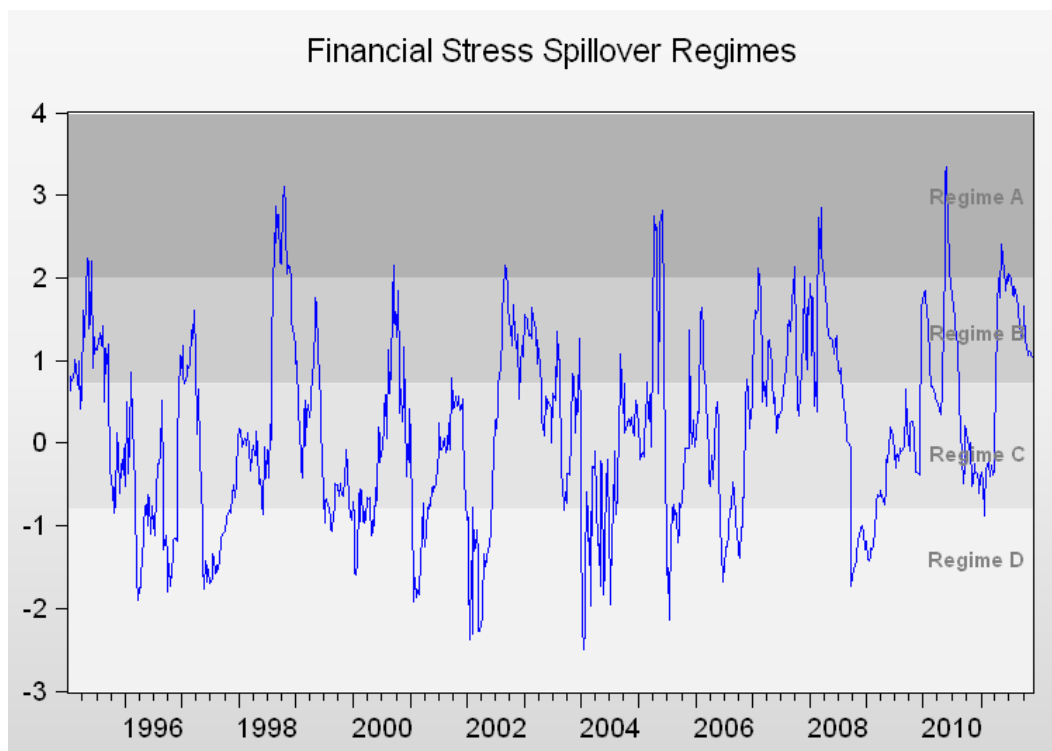
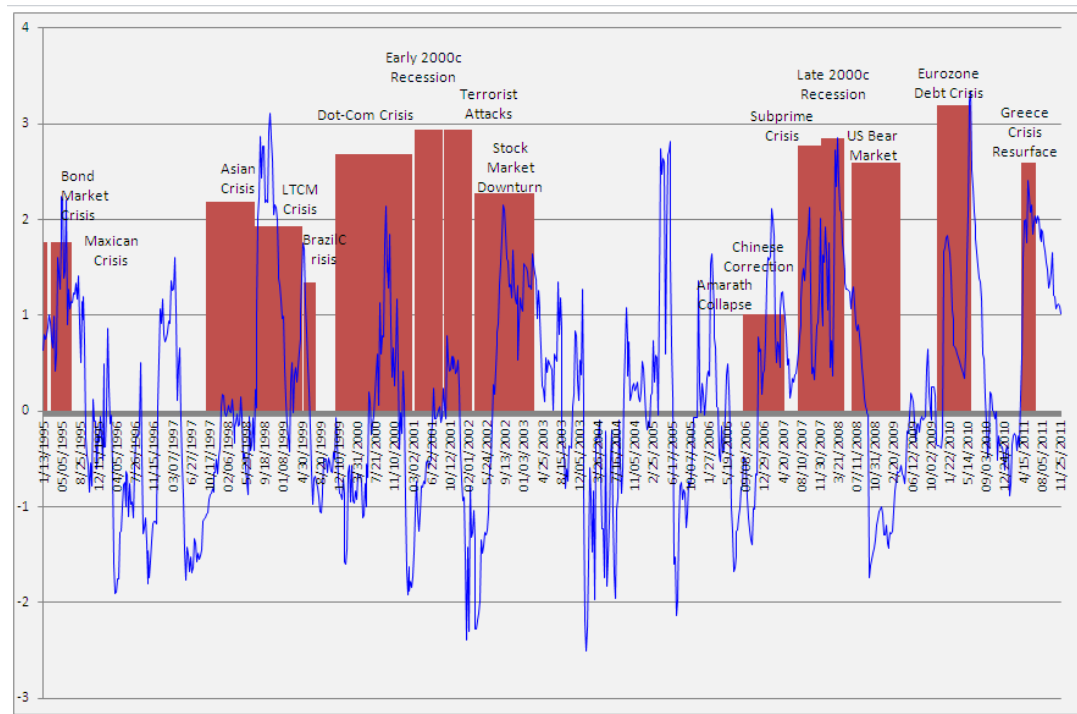


Figure 4: The ‘Scored’ Financial Stress Spillover Index (Z_{FSSI})



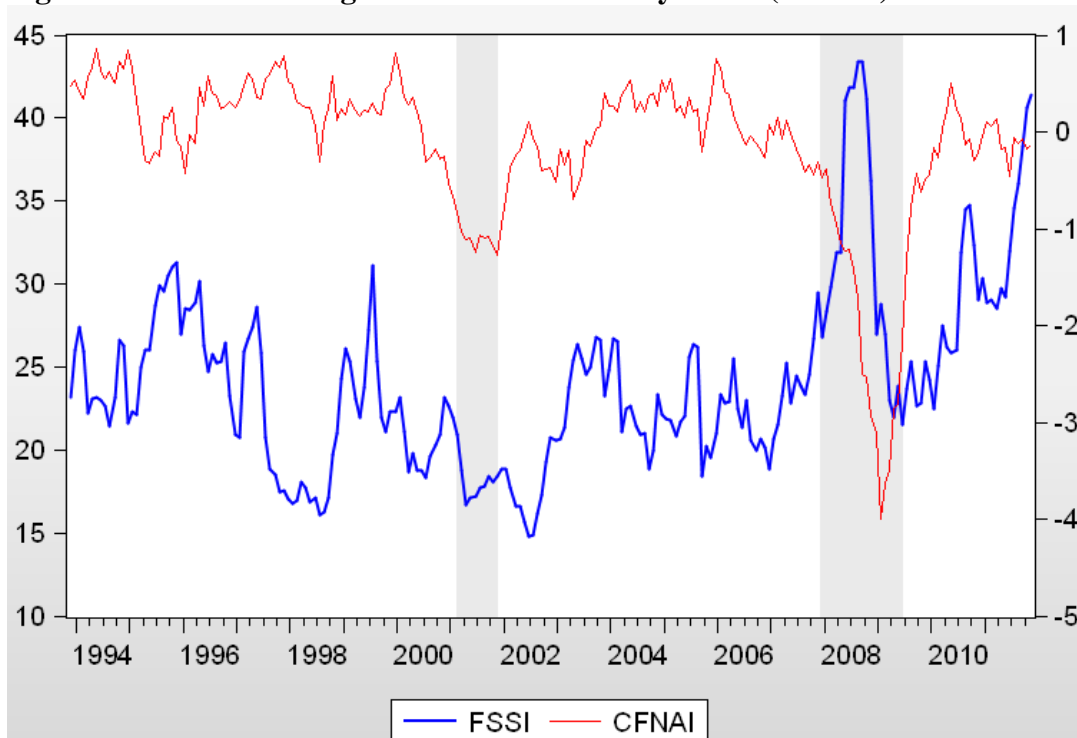
Note: The values are scored FSSI (Z_{FSSI}) which give a measure of how many standard deviations the current FSSI is away from its time-varying mean. It distinguishes four distinct regimes of spillover severity: the “severe spillover” regime A; the “moderate spillover” regime B; the “normal spillover” regime C; the “below-normal spillover” regime D.

Figure 5: Z_{FSSI} vs. Expert's Survey of Financial Crises



Note: The values are scored FSSI (Z_{FSSI}) which gives a measure of how many standard deviations the current FSSI is away from its time-varying mean. The crisis bars are based on the Federal Reserve Bank of Cleveland's expert survey; higher bars reflect the experts' judgement of greater significance and concern.

Figure 6: FSSI vs. Chicago Fed National Activity Index (CFNAI)



Note: Shaded areas represent NBER recessions. A three-month moving average is used for both indices.

Table 3: The Impact of FSSI on Economic Activities

	With FSSI only			With Z only				With both FSSI and Z			Incremental Adjusted R ² [(3) – (2)]
	Adjusted R ² (1)	$\sum \beta_i$	Wald Test	Adjusted R ² (2)	γ_1	γ_2	γ_3	Adjusted R ² (3)	$\sum \beta_i$	Wald Test	
CFNAI	0.1140	-0.0486	17.3278 *** (0.002)	0.9421	0.9620 *** (0.000)	-0.0677 *** (0.001)	0.0096 (0.258)	0.9722	-0.0102	9.8416 ** (0.043)	0.0301
P&I	0.0706	-0.0192	8.2052 * (0.084)	0.1948	0.3473 *** (0.000)	-0.1026 *** (0.001)	0.0420 *** (0.001)	0.2211	-0.0120	6.0559 (0.195)	0.0263
EU&H	0.0483	-0.0115	5.5728 (0.233)	0.7029	0.8130 *** (0.000)	-0.0354 ** (0.046)	0.0157 * (0.066)	0.7018	-0.0030	3.1359 (0.535)	-0.0011
C&H	0.3272	-0.0176	188.2438 *** (0.000)	0.7430	0.7947 *** (0.000)	-0.0035 (0.722)	0.0099 ** (0.025)	0.7533	-0.0043	11.5112 ** (0.021)	0.0103
SO&I	0.0803	-0.0081	10.6218 ** (0.031)	0.0540	0.1217 (0.145)	-0.0451 *** (0.003)	0.0201 ** (0.011)	0.1154	-0.0065	11.5372 ** (0.021)	0.0614

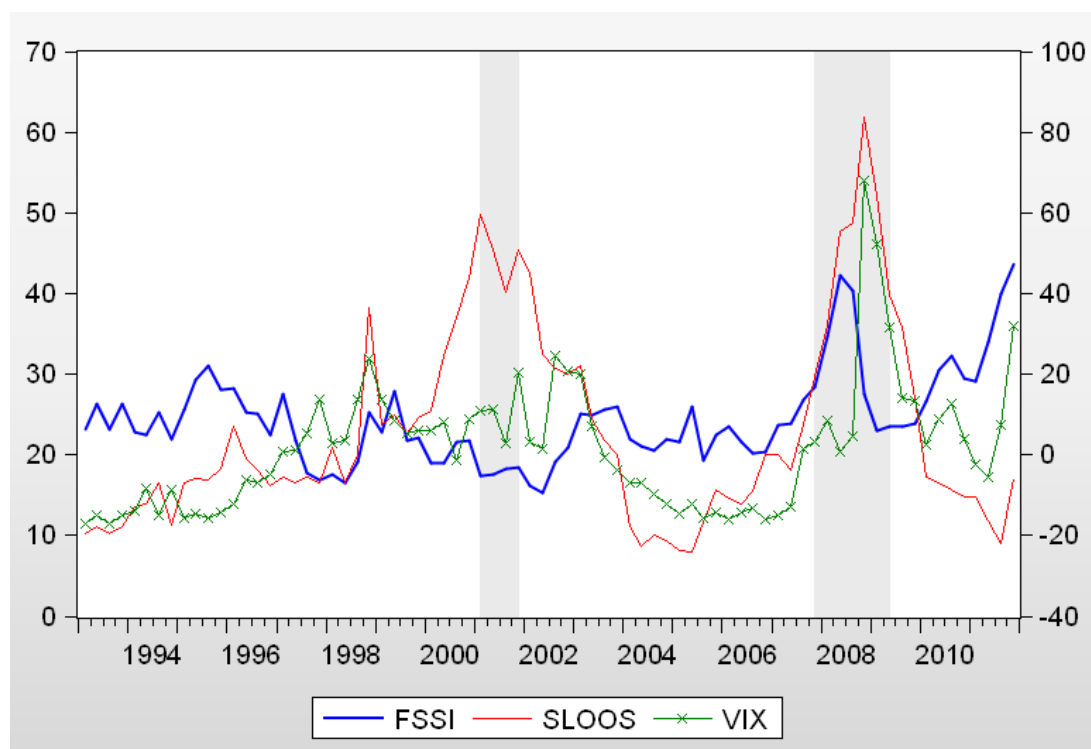
Note: This table reports the adjusted R², the sum of β coefficients on lagged values of FSSI, and a Wald test statistic testing the joint significance of β coefficients from the regression (with FSSI only, with control variables Z only and with both FSSI and control variables Z) in the following equation:

$$ECONACT_t = \alpha + \sum_{i=1}^K \beta_i FSSI_{t-i} + \gamma' Z_{t-1} + \varepsilon_t \quad (7)$$

The number of lags k was chosen using Schwartz criterion. Z includes the first lagged value of dependent variable (γ_1) and other macroeconomic indicators (i.e., the Consumer Price Index (CPI) (γ_2) and the three-month Treasury bill rate (γ_3)). P-values for the joint significance of FSSI lags are in parentheses. Tests for joint significance are conducted using the heteroscedasticity and autocorrelation robust covariance matrix.

The incremental adjusted R² is the difference in explanatory power of a regression that includes lags of FSSI and control variables and a specification that includes only the control variables. ECONACT represents either the 3-month moving average value of the Chicago Fed's National Activity Index (CFNAI) or its four sub-indices for activity in production and income (P&I), employment, unemployment, and hours (EU&H), personal consumption and housing (C&H), and sales, orders & inventories (SO&I), in month t. *, **, *** denote significance at 10%, 5%, and 1% levels, respectively.

Figure 7: FSSI vs. SLOOS and VIX



Note: The changes in FSSI, market uncertainty (VIX), and the Federal Reserve's Senior Loan Officer Opinion Survey (SLOOS) on bank lending standards are presented in this figure. Both FSSI and VIX are expressed as their quarterly averages. Shaded areas represent NBER recessions.

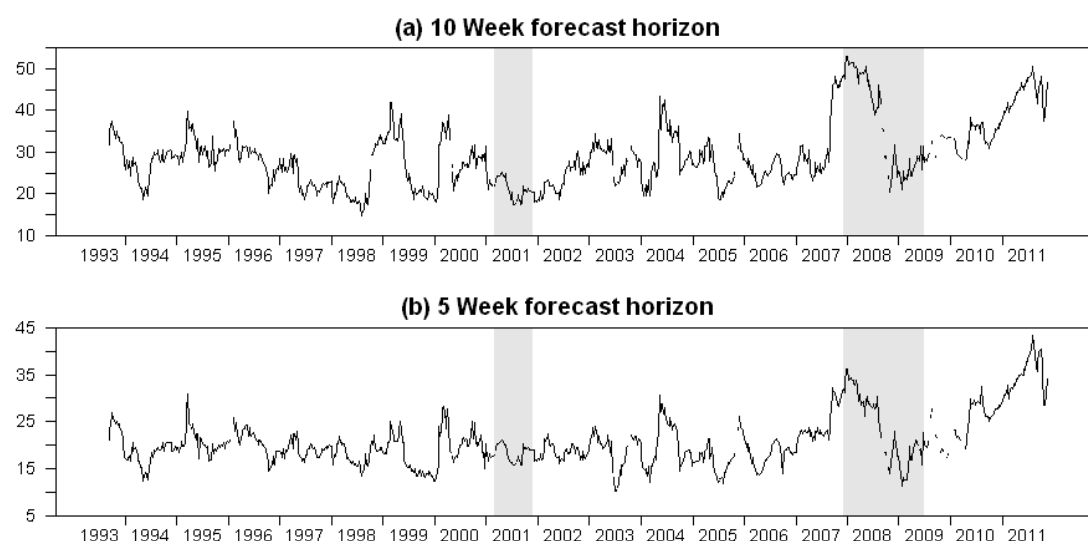
Appendix A: Cleveland Fed's Financial Stress Index (CFSI) construction

Market Sector	Financial Components	Calculation	Notes	Significance
Equity	Stock Market Crashes	$\text{Stock Market Crash}_t = \frac{x_t}{\max\{x_{t-j} j = 0, 1, \dots, 364\}}$	x refers to the S&P 500 Financials Index	Extent to which equity values in the S&P 500 have collapsed over the previous year, expectations about the state of banks
Debt	Covered Interest Spread	$\text{Covered Interest Spread}_t = (1 + r_t^*) - \left(\frac{F_t}{S_t^*}\right) (1 + r_t)$	r* is the 90-day UK T-Bill rate as of noon on day t, F is the 90-day forward rate for the UK-U.S. exchange rate, S* is the spot UK-U.S. exchange rate, and r is the 90-day U.S. T-Bill rate	Uncertainty regarding government bond markets, difficulty in acquiring liquidity for governments signalling the onset of stress
	Corporate Bond Spread	$\text{Corporate Bond Spread}_t = 10CB_t - 10TB_t$	10CB is the 10-year Moody's AAA rated Corporate Bond yield and 10TB is the 10-year Treasury yield	Measures medium-to long-term risk, impressions of risk to corporations in all sectors
	Liquidity Spread	$\text{Bid Ask Spread}_t = \left(\frac{1}{30}\right) \sum_{i=0}^{29} \left[\frac{AP_{t-i} - BP_{t-i}}{\left(\frac{AP_{t-i} + BP_{t-i}}{2}\right)} \right]$	Moving average is calculated over the previous thirty trading days	Changes in the short-term trend of differences in Bid Prices (BP) and Ask Prices (AP) on 3 month T-Bills, measure of an instrument's liquidity
	Commercial Paper-T-Bill Spread	$90 \text{ day Commercial Paper Treas. Spread}_t = (90\text{dayCP}_t) - (3\text{mo TB}_t)$	90day 90-day is Financial Commercial Paper (CP) rate and 3mo TB is 90-day T-Bill secondary market rate	Measures the short-term risk premium on financial companies' debt
	Treasury Yield Curve Spread	$\text{Treasury Yield Curve}_t = \left(\frac{1}{30}\right) \sum_{i=0}^{29} (10\text{yr}_{t-i} - 3\text{mo}_{t-i})$	Thirty-day moving average, difference between three-month T-Bill yields (30mo) on a bond equivalent basis with ten-year constant	Slop of the yield curve as a combination of long-term uncertainty and short-term liquidity needs, predictor of recessions.

			maturity yields (10yr)	
Banking	Financial beta	$Financial\ Beta_t = \frac{cov(r_t _{t-1}^t, m_t _{t-1}^t)}{var(m_t _{t-1}^t)}$	r is banking sector share prices (S&P 500 Financials), m is overall stock market share prices (S&P 500), (t,t-1) are observations from time t to one year prior.	Strain on bank profitability, and potentially solvency, in light of changes in profitability of publicly-traded companies economy wide.
	Bank Bond Spread	$Bank\ Bond\ Spread_t = 10A_t - 10TB_t$	10A refers to ten-year A-rated bank bond yields and 10TB to ten-year Treasury yields (a composite computed by Bloomberg for its C07010Y Index – 10 year A-rated Bank Bond Index)	Perceptions of medium- to long-term risk in banks issuing bonds rated A, medium- to long-range risk to high quality bank profits
	Interbank Liquidity Spread	$Interbank\ Liquidity\ Spread_t = 3mo\ L_t - 3mo\ TB_t$	3mo L is 3 month LIBOR rate and 3mo TB is 90-day T-Bill secondary market rate	TED spread, difference between the LIBOR and Treasuries rate, evidence on counterparty and liquidity risk in interbank lending
	Interbank Cost of Borrowing	$Interbank\ Cost\ of\ Borrowing_t = 3mo\ L_t - FFR_t$	3mo L is 3-month LIBOR and FFR is the Federal Funds Target Rate	Risk premium banks charge to borrow from one another, indicator of counterparty risk.
Forex	Weighted Dollar Crashes	$Weighted\ Dollar\ Crash_t = \frac{x_t}{max\{x \in (x_{t-j} j = 0,1, \dots, 365)\}}$	x is the Trade weighted \$U.S. Exchange Index	Quantifies flight from the U.S. dollar toward foreign currencies, sense of uncertainty or liquidity demand system-wide

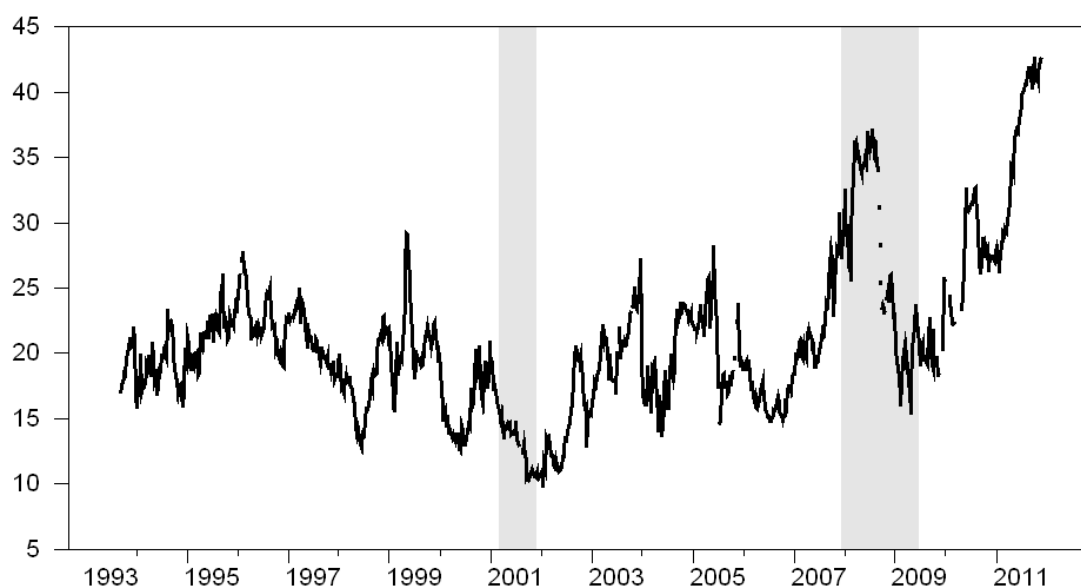
Source: Oet et al. (2011)

Appendix B1: Financial Stress Spillover Indices, 75-week Rolling Windows



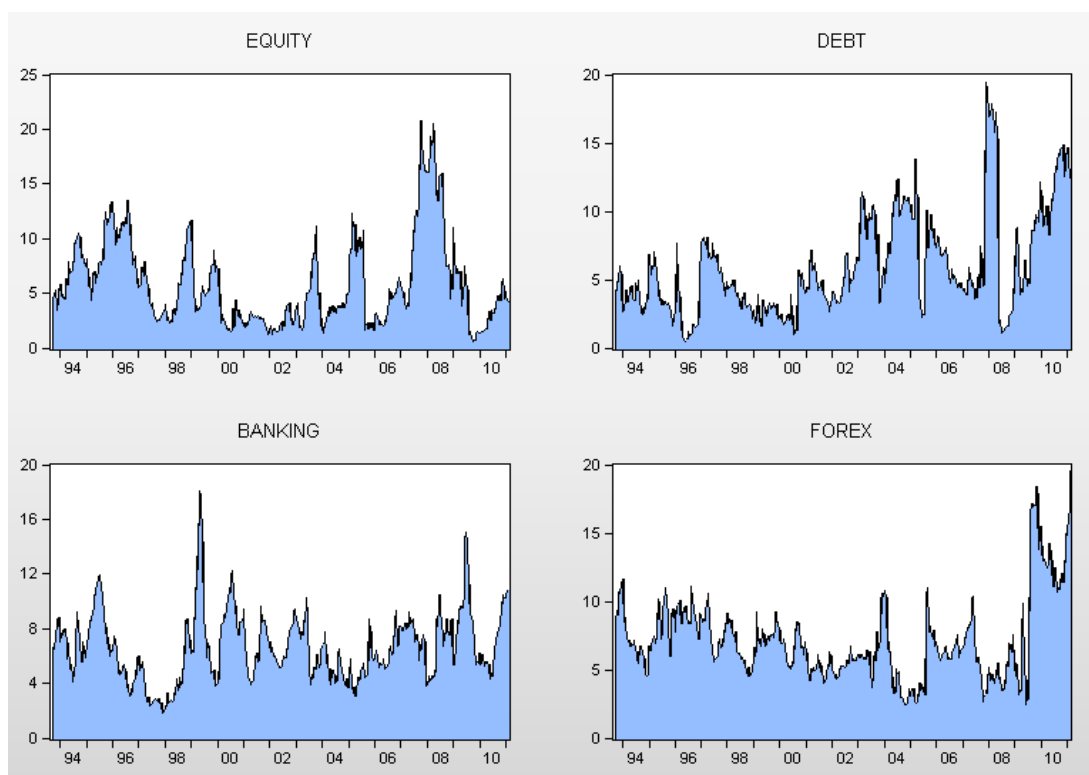
Note: The total financial stress spillover index (FSSI) across four major U.S. financial sectors (equity, debt, banking and foreign exchange markets) is presented in this figure. The values are calculated by re-estimating the second-order VAR weekly, using a 75-week rolling estimation window with 10- and 5-week forecast horizons. Shaded areas represent NBER recessions.

Appendix B2: Financial Stress Spillover Indices, 100-week Rolling Windows, 10- week forecast horizon, Cholesky Variance Decomposition



Note: The total financial stress spillover index (FSSI) across four major U.S. financial sectors (equity, debt, banking and foreign exchange markets) is presented in this figure. The values are calculated by re-estimating the second-order VAR weekly, using a 100-week rolling window with 10-week forecast horizon. Cholesky variance decomposition method is used instead of generalized variance decomposition. Shaded areas represent NBER recessions.

Appendix C1: Directional Financial Stress Spillovers, TO other Markets



Appendix C2: Directional Financial Stress Spillovers, FROM other Markets

